Smothered Scampi: Taphonomy of Lobsters in the Upper Cretaceous Bearpaw Formation, Southern Alberta

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Phosphatic concretions, containing remains of the lobster Palaeonephrops browni (Whitfield), are described from the Upper Cretaceous Bearpaw Formation of southern Alberta. Two modes of burial are interpreted to have enhanced the preservation potential of the lobsters: (1) burial of remains by volcanic ash, and (2) burial of remains within burrows due to sediment injection during storms. The latter mode of burial is indicated for the majority of the specimens studied, suggesting that the exceptional preservation of Palaeonephrops, and probably some other fossil decapod taxa may have been more strongly influenced by their life-habits than previously assumed. Within-burrow preservation of lobster specimens also demonstrates that obrution is not only important for the preservation of faunal elements residing on the sea-floor, but can also bias the preservation of some deep infaunal taxa. Following rapid burial, the preservation potential of the lobster remains was further enhanced by virtue of its phosphate-bearing cuticle, upon which, early diagenetic phosphate cements were preferentially precipitated. Further phosphate precipitation resulted in the entombment of the remains within phosphatic concretions, further protecting them from destructive taphonomic processes.

Keywords: BURROWS, CONCRETIONS, CRETACEOUS, CRUSTACEANS, DECAPODS, DIAGENESIS, PHOSPHATE, TAPHONOMY.

Introduction

Marine mudstone successions of the Upper Cretaceous Bearpaw Formation contain abundant phosphatic concretions that preserve remains of the lobster Palaeonephrops browni (Whitfield). Although well-preserved specimens of this lobster have long been known to occur in the Bearpaw Formation (Whiteaves, 1887, 1889; Feldmann et al., 1977; Feldmann & McPherson, 1980) they have received little attention in context of their taphonomy.

As a general rule, lobsters and most other decapod crustaceans, are poorly represented in the fossil record due to the
susceptibility of their organic-rich, multi-element, exoskeletons to decay, disarticulation and dissociation (Bishop, 1986, Plotnick, 1986; Allison, 1988a). Clearly, the preservation of their remains requires unusual circumstances in which the remains are protected from dissociation by scavengers and bioturbators and the decay of organic cuticle components is inhibited. Such conditions are most readily achieved by the deep burial via rapid sedimentation and the precipitation of diagenetic of minerals respectively (Feldmann & McPherson, 1980; Allison, 1988a; Briggs et al., 1993).

The exceptional preservation of the remains of Palaeonephrops is particularly intriguing in that their quality of preservation commonly surpasses that of the more robust, shelly remains of the associated fossil mollusc shells in the Bearpaw Formation. In this paper, the factors that led to the exceptional preservation of corpse remains are investigated, with an emphasis on the possible taphonomic consequences of the burrowing habits of nephropid lobsters.

**Stratigraphy and Materials**

The Bearpaw Formation is a southeastward-thickening wedge of marine sediments, deposited during the Late Campanian-Early Maastrichtian transgressive pulse of the Western Interior Sea of North America (Kauffman, 1977). In southern Alberta, the Bearpaw Formation consists of dark grey, concretionary mudstone, minor units of sandstone, and prominent bentonite seams (Russell & Landes, 1940). The Bearpaw Formation is underlain by the primarily non-marine sediments of the Judith River Group (Eberth & Hamblin, 1993) and overlain by marginal marine sediments of the Horseshoe Canyon, Blood Reserve and Eastend Formations (Russell & Landes, 1940).

Remains of Palaeonephrops browni, were observed in phosphatic concretions, in the lower part of the Bearpaw Formation (Baculites compressus and Baculites cuneatus Zones) at six outcrop localities in southern Alberta (Figures 1,2). The concretions occur primarily in sparsely fossiliferous intervals of bentonitic and non-bentonitic (Figure 2) mudstones separating horizons of bivalve-rich shell concentrations and cm-scale siltstone/sandstone beds (Tsujita, 1995a, 2001). Within these intervals, the phosphatic concretions have a scattered distribution, showing no tendency to occur in distinct horizons, and reach densities of up to 5 concretions per m² of vertical section. Less commonly, lobster remains are also preserved in phosphatic concretions within well-developed bentonite seams (Figure 2).

Fifty lobster-bearing concretions were collected by the author from the localities noted above, ten from well-developed bentonite seams and forty from mudstone intervals. The concretions were cut, polished, and etched with dilute (5 %) hydrochloric acid to reveal their internal characteristics. Approximately thirty additional lobster-bearing concretions, housed in the Royal Tyrrell Museum of Drumheller, Alberta, Canada, were also studied.

All of the phosphatic concretions examined contain a dark grey- to brown-coloured core and a light grey-coloured rim, determined by X-ray diffraction analysis to
contain francolite and mixed francolite-aragonite (or less commonly, francolite-calcite) cements respectively. The cuticle of *Palaeonephrops* is preserved as a dark brown-to-black-coloured film of francolite. Some concretions are surrounded by siderite-cemented jackets, that weather to a rusty brown colour.

**Depositional environment and faunal associations**

Mudstone successions containing *Palaeonephrops* are interpreted to have been deposited well below fair-weather wave base, in deep offshore areas of the Bearpaw Sea (for further discussion see Tsujita, 1995a, 2001). A pervasively bioturbated fabric is observed throughout these successions, which suggests that the overall rate of sedimentation was sufficiently low to allow complete biological reworking of deposited mud.

Although almost completely overprinted by bioturbation, erosion surfaces (marked by the truncation of *Chondrites*), and mm- to cm-scale vertical variations in silt content in the lobster-bearing mudstone intervals suggest that storms episodically affected the Bearpaw sea-floor. This interpretation is supported by the interruption of the lobster-bearing mudstone intervals by sandstone/siltstone beds and shell-rich horizons that bear more obvious evidence of storm sedimentation (Tsujita, 1995a, 2001).

The molluscan fauna associated with the fossil lobsters is invariably sparse, scattered and restricted in diversity. Nektic
faunal elements include the ammonites *Baculites* and *Placenticeras*. Rarer elements include gladii of *Actinosepia*, bone fragments and fish scales. The benthic assemblage is dominated by three bivalve genera, the infaunal deposit-feeder *Nucula*, and the reclining epifaunal suspension-feeders *Inoceramus* and *Gervillia*, all of which were adapted to living in/on unstable mud (Stanley, 1970; Bottjer, 1981; Savazzi, 1984). Less common elements are shells of deposit-feeding bivalve *Yoldia* and the carnivorous naticid gastropod *Lunatia*. Shells of the suspension-feeding bivalve *Arctica* are also present in some of the siltier mudstone intervals.

Due to the tendency of the Bearpaw mudstones to weather to fine flakes, trace-fossils are difficult to observe. However, close examination of the flakes indicates a mottled background fabric superimposed by faint traces of *Chondrites* and *Helminthopsis*, indicating that the sediment was too soupy to preserve discrete burrows at the sediment-water interface (Rhoads, 1970) but sufficiently firm at depth to preserve such features.

As discussed by Tsujita (1995a, 2001), vertical diversity patterns of shelly macrofauna indicate fluctuations in oxygen
Figure 3. A. Complete specimen of loosely enrolled *Palaeonephrops browni*, preserved in discoidal concretion (prepared upper surface), showing positions of carapace (ca), major chela (ch), walking legs (w) and tail fan (t). Loss of skeletal material in thorax is due to weathering. Scale bar: 2 cm. B. Polished section of discoidal lobster-bearing concretion showing faint, undulose laminae (l). Compressed lobster cuticle is preserved as a thin, black film near the top of the concretion. Scale bar: 1 cm.
levels on the Bearpaw sea-floor. However, as indicated by the restricted abundance and diversity of both body- and trace-fossils, such fluctuations appear to have been less dramatic in the lobster-bearing mudstone intervals than in the siltier/sandier units of the Bearpaw Formation that record shallower water conditions, and produced dysoxic conditions at best.

The shell-rich horizons that punctuate the mudstone intervals contain faunal assemblages that are completely different from those observed in the lobster-bearing mudstones, and are generally dominated by the remains of small, opportunistic, suspension-feeding bivalves such as Protocardia, Volsella, Phelopteria and Liopistha. Such horizons record brief episodes of significantly increased oxygenation and sediment stability that promoted the establishment of dense benthic communities. Shells produced during these colonization events were further concentrated by hydraulic disturbance during storms to ultimately form the shell-rich horizons (Tsujita, 1995a, 2001). The absence of similar shell concentrations containing typical faunal elements of the lobster-bearing mudstone intervals is probably more a function of the scarcity of shelly molluscan remains available for reworking than the absence of storm disturbance on the sea-floor.

Bentonite-hosted lobster concretions

The ten phosphatic concretions collected from well-developed bentonite seams are discoidal in shape, flattened in the plane of bedding, with diameters of 7-15 cm. The discoidal shape of the concretions conforms to the outline of loosely enrolled lobster remains contained within (Figure 3a). All specimens are preserved lying on one flank, with the tail broadly curved and legs extended ventrally. The carapace is detached from the abdomen and rotated dorsally, away from relative to the rest of the exoskeleton.

Sections of discoidal concretions, cut perpendicular to bedding, generally reveal a strongly bioturbated fabric with indistinct mottles and occasional trails of phosphatized faecal pellets. Concretion fabrics that are less disturbed by bioturbation show traces of horizontal, undulose laminae (Figure 3b).

Mudstone-hosted lobster concretions

In contrast to the bentonite-hosted concretions, mudstone-hosted, lobster-bearing phosphatic concretions are oblong (ellipsoidal to cylindrical) in shape, with cross-sectional diameters of 5-10 cm. Concretion length ranges from 5-10 cm in ellipsoids to 20-50 cm in cylindrical forms. Similar, cylindrical concretionary bodies with branches have also been observed in the lobster-bearing mudstone intervals (Figure 4).

The majority of the oblong concretions collected from mudstones preserve a uniformly bioturbated fabric dominated by the trace-fossils Chondrites, Planolites and Helminthopsis (Figure 5). Although the contained lobster remains can be identified by their dark colour and distinctive surface texture, most show some degree of fragmentation by the organisms responsible for the bioturbation. Even in the most severely disturbed material,
however, the skeletal fragments show little dispersion (Figure 5).

Due to the skeletal fragmentation and fabric overprinting by bioturbation, most specimens lack the evidence required to allow the interpretation of their mode of burial. Fortunately, however, three ellipsoidal concretions and seven cylindrical concretions collected by the author preserve fully articulated lobster specimens and original sedimentary fabrics that provide some insight to burial processes.

In marked contrast to lobster remains collected from bentonite seams, well-preserved lobsters within mudstone-hosted concretions occur in an outstretched position, with major chelae directed forward, abdomen more or less extended and tail fan directed downward or tightly flexed beneath the abdomen (Figures 6, 7). The walking legs are sharply bent, with the distal portions directed slightly forward and in close proximity to the flanks of the carapace (Figure 7). The majority of the concretions examined contain a single lobster, but four concretions (one collected by the author, and three observed in the Royal Tyrrell Museum collections), were noted to contain two individuals preserved in an end-to-end configuration (Figure 7).

Along with well-preserved lobster remains, the concretion matrix preserves sedimentary features that differ completely from those associated with specimens found in bentonite seams. Common to all of the oblong concretions containing complete lobster specimens is a distinctive sedimentary fabric, characterized by small (0.5-5 mm diameter), randomly oriented angular mud clasts, and faecal pellets, set in a cloudy mud matrix with faint, contorted laminae. This fabric was noted to extend all the way to the concretion margin in ellipsoidal concretions that contain well-preserved lobsters (Figure 8). Cross-sections of cylindrical concretions, however, show some restriction of the chaotic fabric to the interior of the concretion and the preservation of a bioturbated fabric near the concretion margin (Figure 9). This bioturbated fabric

Figure 4. Branched phosphatic concretion from lobster-bearing mudstone interval, St. Mary River section (Royal Tyrrell Museum specimen TMP 87.120.1). Scale bar: 5 cm.

Figure 5. Polished cross section of ellipsoidal, lobster-bearing concretion showing abundant burrows. Note lack of dispersion of fragmented lobster remains, despite intense disturbance by bioturbation. Scale bar: 1 cm.
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is characterized by faint traces of *Chondrites* and *Helminthopsis* superimposed on a mottled background, therefore resembling the ichnofabric preserved in the host mudstones.

A sharp, strongly curved contact delineates the inner chaotic and outer bioturbated fabrics, truncating the diminutive burrows preserved in the latter. In places, the sharp contact and details of the adjacent sedimentary fabrics, cross the diffuse boundary delineating the dark-coloured, francolite-cemented core and lighter coloured francolite-aragonite/calcite-cemented concretion rim (Figure 9).

In addition to lobster remains, rare bone fragments, fish scales, and gladii of *Actinosepia* are preserved in phosphatic concretions within mudstone intervals. However, concretions containing such remains have never been observed to contain lobster specimens or to preserve the distinctive chaotic fabric apparent in the lobster-bearing specimens.

The sediment fills of some ammonoid body chambers and cavities of articulated bivalves have also been cemented by phosphate, invariably preserving masses of phosphatized faecal pellets. Unlike the lobsters, however, molluscan remains are rarely surrounded by a protective phosphate-cemented jacket, rendering them prone to dissolution. Thus, the molluscan remains, which would normally be expected to have the highest preservation potential of all shelly megafaunal elements in mudstones of the Bearpaw Formation, are generally less well-preserved than the lobster specimens entombed within concretions.

Figure 6. Complete specimen of *Palaeonephrops browni* in outstretched position, preserved in ellipsoidal phosphatic concretion (prepared upper surface). Scale bar: 2cm.
Interpretation of bentonite-hosted lobster concretions

The configuration of lobster remains preserved in the discoidal concretions (Figure 3a) collected from well-developed bentonite seams is identical to that observed in exuviae of the modern lobster *Nephrops norvegicus* (Linnaeus) (Schäfer, 1951). In the process of moulting, *Nephrops* severs its exoskeleton between the carapace and the abdomen. As the lobster emerges from its moult, the cephalothorax is rotated dorsally, away from the rest of the exoskeleton, resulting in what is termed Salter’s position (Schäfer, 1971, p. 435). This position is commonly observed in moults of fossil nephropids, most notably in the genus *Hoploparia* (e.g. Glaessner, 1969; Bishop & Williams, 1986; Feldmann and Tschudy, 1987). The broad curvature in the abdomen and ventral extension of appendages, relative to the carapace (Figure 3a) indicates that the remains were laterally unobstructed on the sea-floor prior to burial. This is verified by the occasional preservation of horizontal bedding structures in the lobster-bearing concretions (Figure 3b).

As indicated by their restriction to well-developed bentonite seams, the preservation of *Palaeonephrops* mouls was enhanced by the elevated sedimentation rates associated with ash-fall events. Such events appear to have been necessary for moult remains to be buried sufficiently rapidly to preclude significant disturbance by epifaunal scavengers and other agents of disturbance (Heikoop et al., 1996).

Interpretation of mudstone-hosted lobster concretions

Interpretation of remains

Well-preserved lobster specimens collected from mudstone intervals of the Bearpaw Formation are most appropriately interpreted as corpses since they preserve the natural articulation of the cephalothorax and abdomen expected for such remains (Figures 6, 7). None are preserved lying on...
Figure 8. Polished section of ellipsoidal lobster-bearing concretion, showing abundance of angular mud-clasts (mc) and phosphatized faecal pellets (fp). One walking leg (wl) is visible in cross section. Note cheliped (cp) that partially collapsed after burial (fragments of cuticle are preserved inside undamaged portion). Also note clast of laminated siltstone (l); such lamination was not observed in the mudstone surrounding the concretion (inset: enlargement of silty clast). Scale bar of main photo: 1 cm.
their side and loosely enrolled as observed in the bentonite-hosted specimens. Although the majority of the lobster specimens have suffered extreme fragmentation by bioturbation, the minimal dispersion of these fragments suggests that the oblong shape of the surrounding concretions reflects a linear arrangement of skeletal elements similar to that observed in the better-preserved lobster specimens. In any case, the fundamental differences in lithology and the types of remains preserved within the concretions indicate that mudstone-hosted specimens must be investigated in a different taphonomic context than the bentonite-hosted specimens.
Figure 10. Subsurface obrution model for the burial and preservation of *Palaeonephrops*. A. Lobster occupying simple, unlined burrow in offshore mud. Firm, compacted mud underlies surficial layer of water-rich surficial mud containing faecal pellets. B. Seafloor disturbance by storms mobilizes soupy, pelleted, surficial mud, rips up angular mud clasts from the sea-floor and injects these components into lobster burrow, smothering its inhabitant. C. Phosphatic concretion forms around lobster remains. Details of the burrow wall and burrow fill are preserved within concretion matrix, but are not readily observed in host mudstones due to poor lithologic contrast.
The overall morphologies of both simple (Figure 7) and branched (Figure 4) forms of cylindrical, mudstone-hosted, concretions suggest that the growth of phosphatic concretions in the Bearpaw mudstones was directed along large burrows. In accordance with this interpretation, the most plausible explanation for the sharp, curved contact that separates the inner chaotic and outer bioturbated fabrics in cross-sections of the cylindrical concretions (Figure 9) is that it represents the wall of an unlined burrow. Furthermore, the outstretched posture of the lobster remains (Figure 7), and the end-to-

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**Figure 11.** The scattered distribution of lobster-bearing concretions in mudstone intervals is explained by variations in the depths of lobster burrows. A. Sediment injection of burrows during a burrow fill event buries lobsters at multiple intervals. B. Ellipsoidal and cylindrical concretions that grow around lobster remains have a scattered distribution.
end configuration of multiple lobsters, suggest that the remains were preserved in a confined space, such as a tube-shaped burrow.

Observations on the ecology of the extant *Nephrops norvegicus* (Linnaeus) reinforce the interpretation that its ancient relative *Palaeonephrops* was a burrower. As interpreted for *Palaeonephrops*, *Nephrops* inhabits quiescent subtidal marine habitats where sea-floor mud is soft and unstable at the sediment-water interface but sufficiently cohesive at depth to permit the excavation of unlined burrows (Rice and Chapman, 1971). In their simplest form, *Nephrops* burrows consist of a simple tunnel with one or two apertures leading to the sediment-water interface (Dybern & Hoiseter, 1965; Chapman & Rice, 1971; Rice & Chapman, 1971), but are commonly branched (Rice & Chapman, 1971; Atkinson, 1974). Although apertures are not been preserved, the elongate concretionary bodies preserved in the Bearpaw Formation do resemble the simple tunnels produced by *Nephrops* (Figure 10a).

**Mode of burial**

Consistent with the sedimentary fabric of the host mudstones, and the substrate requirements for *Nephrops*-type burrows, the superimposed ichnofabrics observed in the concretions (i.e., lobster burrows cut into the *Chondrites-Helminthopsis* ichnofabric superimposed on mottles) record the increasing cohesion of mud with increasing depth of burial and compaction (Bromley, 1990). The contrasting cohesive properties of surficial versus subsurficial (and more compacted) muds of the Bearpaw sea-floor are also reflected in the texture and fabric of the sediment fill of the lobster burrows. The mud matrix of the burrow fills, presumably derived from the un lithified sea-floor muds, must have been very fluid to completely fill the burrows, produce the convoluted laminae, and retain the random orientation of the mud clasts and faecal pellets. On the other hand, the angular mud clasts must have been derived from more cohesive substrata that had experienced some degree of compaction prior to being incorporated into the burrow fill.

Tsujita (1995b) originally speculated that the mud clasts were dislodged from the burrow wall due to burrow collapse. However, a more thorough inspection of the clasts has since indicated significant lithologic differences between the some of the clasts and the burrowed substrate. For example, one of the clasts in figure 8 preserves laminae of silt that, despite an extensive search, were not found in the mudstone surrounding the concretion. The clasts are therefore more likely to have been derived from firm substrata exposed on the sea-floor surface and transported into the burrows together with the fluid mud.

The fabric of the burrow fills, together with the exceptional preservation of the contained lobster remains, all point to a high degree of hydraulic disturbance, as would be expected during storms. High-energy conditions associated with storms would have stripped the sea-floor of its soupy, pelleted, surficial muds, in some areas exposing and eroding the firmer, compacted muds below them to produce angular rip-up clasts.

The chaotic orientation and distribution of the mud clasts within the
burrow fills indicate that the injection of sediment into the lobster burrows was very rapid, thereby supporting a storm-based interpretation. As indicated by studies by Wanless et al. (1988) and Tedesco & Wanless (1991), burrows are prone to sediment infill during storms due to enhanced sediment mobilization and wave pumping, producing tubular tempestites. Admittedly, the lobster burrow fills described here do not contain high concentrations of shell material as is typical of most tubular tempestites (e.g., Wanless et al., 1988; Monaco & Garassino, 2001; Monaco & Giannetti, 2002; Zuschin & Stanton, 2002), but as stated for the absence of shell beds, this could merely reflect the scarcity of shell material available on the Bearpaw sea-floor for reworking.

The conspicuous absence of lobster corpse remains in bentonite-hosted concretions suggests that sedimentation rates associated with ash-fall were insufficient to prevent lobsters from escaping death by smothering even though they were sufficiently high to preclude the destruction of moults. In contrast, burrows were apparently of adequate depth to prevent lobsters inhabiting them from escaping when rapidly injected with sediment. The preserved corpse remains therefore record a unique type of rapid burial or obrution that, instead of biasing the preservation of epifauna as more typically recorded in such events (Seilacher et al. 1985; Brett & Seilacher 1991), enhanced the preservation of a single infaunal taxon.

Deep burial within burrows would have provided the remains of the smothered lobsters some degree of protection against the agents of disturbance that would have otherwise promoted their complete destruction on the surface of the sea-floor. Even so, the extensive fragmentation of skeletal elements in many of the concretions indicates that the remains were not immune to disturbance by bioturbation if their surrounding burrows were too shallow.

The rapid burial of Palaeonephrops within burrows explains why its fossil remains are not restricted to laterally traceable horizons as would otherwise be expected for events of obrution at the sediment-water interface. Maximum depths of modern Nephrops burrows have been noted to range from 18 to 33 cm below the sediment-water interface within a single population (Chapman & Rice, 1971) and it is not unreasonable to assume that the depths of Paleonephrops burrows varied to a similar degree. It follows that a single obrution event could have buried lobsters at slightly different depths, producing an obrution assemblage that significantly deviated from a single horizontal plane (Figure 11). The scattered distribution of the lobster-bearing concretions therefore does not conflict with a storm-related interpretation. High densities of lobster-bearing concretions in thicker stratigraphic intervals may reflect either more frequent events of burrow infill or faunal epiboles (Brett & Baird, 1997) that increased the probability of lobster specimens to be buried and preserved during any given event.

Lastly, as indicated by studies by Chapman & Rice (1971), it is not uncommon for a single Nephrops burrow to contain more than one lobster. Thus, the occurrence of two lobsters in a few of the Bearpaw concretions is consistent with observations on burrow co-habitation by
nephropid lobsters.

**Diagenetic processes**

The phosphate incorporated in the diagenetic cements of the lobster-bearing concretions was probably derived from disseminated phosphate-bearing components within the host sediment. Phosphate may be released from decaying organic matter and iron hydroxides under anoxic conditions (e.g., Baturin, 1971; Burnett, 1977; Benmore et al., 1983; Lucas & Prévôt, 1991). If the dissolved phosphate reaches high enough concentrations in sediment pore-waters, it may be precipitated interstitially (Burnett, 1977). Large-scale phosphatization is generally thought to require a combination of conditions that include severe reductions in sedimentation rate, high primary productivity, and anoxia (e.g., Veeh et al., 1973; Burnett, 1977; Lucas & Prévôt, 1991). However, the release of dissolved phosphate under less extreme conditions can reach sufficient levels to precipitate locally on phosphate-bearing substrata (Allison, 1988a,b). This scenario appears reasonable for the environmental conditions interpreted for the Bearpaw mudstones, which bear evidence of relatively low sedimentation rates and dysoxic benthic conditions (Tsujita, 1995a), and contain phosphate-bearing lobster remains, among other phosphatic faunal elements. The initial decay of organic components in phosphatic remains such as lobster cuticle may have also enhanced microbial activity within, and immediately around, the remains, producing highly reducing pore-water conditions, thus further promoting local phosphate precipitation. In any case, preferred phosphate precipitation on phosphate-bearing faunal remains such as lobster remains during the early diagenesis clearly offered the remains some protection from the diagenetic processes that affected the exposed shell surfaces of associated molluscan remains. As implied by the cement compositions of other concretions in the Bearpaw Formation (Tsujita, 1995a), the aragonite/calcite cemented concretion rims and the siderite-cemented jackets that surround some of the phosphatic concretions probably record the passage of concretions through the diagenetic zones of sulphate reduction and methanogenesis with increasing burial.

The close approximation in concretion shape to the general outline of the contained lobster(s) indicates that phosphate precipitation was centred on the lobster remains. However, the fact that sediment induration within some cylindrical concretions extends several centimetres in front of, and behind, the lobster corpse remains, indicates that concretion growth continued along the burrow axis. This probably reflects the greater ease of the concretion to grow in the water-rich burrow fill than in the firmer, dewatered, sediment surrounding it. Accordingly, the extension of the chaotic burrow fill to the concretion margin in some ellipsoidal concretions may simply reflect the failure of some concretions to grow beyond the burrow wall. The ellipsoidal shape of these concretions further indicates that concretion growth, focused around the lobster remains, ceased before the shape of the burrow could impose a significant influence.

Fabric overprinting by later bioturbation would have obliterated the
necessary contrasts in water content between the burrow fill and host substrate required for the growth of cylindrical concretions. It follows that the direction of concretion growth in sediment preserving this overprinted fabric would have been more uniform, following the general periphery of the mass of lobster fragments. This could explain why the vast majority of the concretions, which contain fragmented lobster remains and a thoroughly bioturbated fabric, are consistently ellipsoidal in shape. Admittedly, it is also possible that some of these lobster corpses were not buried within burrows, but instead, were affected by obstruction at the sediment-water interface. However, the scattered distribution of the concretions and the circumstantial evidence provided by cylindrical lobster-bearing concretions suggests that the injection of burrows by sediment was the most effective means of burial for the lobsters.

**Summary and Implications**

Marine mudstone successions of the Upper Cretaceous Bearpaw Formation yield abundant phosphatic concretions, many containing well-preserved specimens of the lobster *Palaeonephrops browni* (Whitfield). The preservation of complete lobster specimens required immediate isolation of articulated lobster remains from the sediment-water interface where agents of disturbance and decay were most operative. Taphonomic evidence suggests that the preservation of moult remains of *Palaeonephrops* was enhanced by the high sedimentation rates associated with volcanic ash-fall. More significantly, the preservation of corpse remains was influenced by deep burial within dwelling burrows.

Direct associations of fossil decapods and burrow systems have generally been regarded as exceptional. This is despite the fact that a wide variety of fossil decapods have been found associated with burrows. These include linuparid and nephropid lobsters (e.g., Bishop, 1986; Bishop & Williams, 1986; Pemberton et al., 1984), glypaeid lobsters (e.g., Sellwood, 1971), crabs (e.g., Richards, 1975), and thalassinid shrimps (e.g. Waage, 1968; Förster & Barthel, 1978; Bishop, 1986; Monaco & Garassino, 2001). The interpretation that subsurface obrution within burrows was a dominant factor in the preservation of *Palaeonephrops* corpse remains suggests that within-burrow preservation of burrowing decapods might be more common than previously assumed. Within-burrow preservation could be easily overlooked, particularly in cases where the lithological characteristics of the burrow fill are similar to those of the burrowed substratum. This is especially relevant to many Cretaceous mudstone units of the North American Western Interior, whose weathering characteristics further mask colour contrasts that might otherwise reveal the presence of decapod burrows and other subtle features of sedimentary fabric (Figure 10c). Indeed, early diagenetic concretions may be the only media capable of preserving evidence of within-burrow preservation of decapods in some of these sedimentary units.

This study also underscores the importance of life-habit in the preservation of some fossil organisms and that emphasizes that the effects of obstruction in
marine settings are by no means limited to organisms living at the sediment water interface. In the case of Palaeonephrops, the burrowing lifestyle of the decapod influenced its cause of death, the rate at which its remains were buried and the diagenetic processes that ultimately ensured the survival of its remains. It is likely that the preservation of remains of other burrowing decapods were similarly influenced by the burrowing life-habits.

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